Milankovitch Cycles in the Distant Past

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In prehistory celestial movement was tracked and scrutinized, as demonstrated by monuments like Stonehenge and the Mayan observatories. From the knowledge gained in this pursuit, our ancestors decided when to plant, when to harvest, and when to expect a change in the weather. In modern history we have examined, measured, and recorded our weather, dutifully mapping and modeling our environment and climate. Our records over this relatively short span of time show us that our climate is changing. Some would say more quickly than is desired and more quickly than it ever has before.

We are all aware of the daily and annual demonstrations of Earth's orbit affecting our climate. After all, this is the governing force of day and night and seasonal change. Year after year, the seasons cycle, yet no year is exactly like the year before. Over long periods of time this gradual change accumulates and leaves us with very different environmental conditions than those that existed at our initial point of reference. There are many reasons climate can change, both anthropogenic in the post-industrial world, and natural causes over the history of the Earth. A very important driving force in the change in long term climate is the variation in our orbit, which changes the amount of energy added to our system by the Sun.

It was suggested by James Croll in the late 1800's that change in glaciation was a function of changes in the Earth's orbital parameters (Croll, 1875). This argument was taken up by Milankovitch in 1941 who demonstrated three aspects of astronomical control of climate. He studied celestial mechanics, quantifying planetary movement and isolating elements of orbital movement. He also modeled the Earth's insolation, how much solar energy is received by the Earth's surface. Finally, he investigated the impact of the energy supply on the Earth's climate. This work is the foundation of modern understanding of orbital controls of climate.

Milankovitch's Theory

Milankovitch broke our orbit into three discreet sets of movement. These sets function in a quasi-periodic way. While not perfectly rhythmic, they do have one very important characteristic: they are predictable. As the three function, their signals often commingle, affecting the strength of their expression. Sometimes their strengths are moderated, sometimes enhanced. This can make them difficult to distinguish, but not impossible. The three elements Milankovitch suggested impacted our insolation were obliquity, eccentricity and precession.

Obliquity is the changing tilt of the Earth's axis. This tilt is the driver of seasonal change. The tilt, currently 23.6° away from the plane formed by the Earth's orbit, causes regular, cyclic, variation in the intensity of solar radiation reaching the Earth's surface. This tilt varies from 22.2° to 24.5°. As tilt, obliquity, increases (toward 24.5°) seasons become more intense. As obliquity decreases, as the Earth's equator becomes closer to parallel to the plane made by Earth's orbit, seasons are suppressed because there is less difference in the angle of incidence of the solar radiation as the Earth moves around the Sun. This means milder conditions globally and increased glaciation at the poles. The cycle proceeds at a rate of one cycle per 41,000 years. As you can imagine, as tilt increases the parts of the globe that are the most affected are the poles. These areas are turned farther away from radiation for longer each winter season than they were when the tilt was less extreme. This also means that summers are longer and hotter. These hotter summers generally cause any accumulated snow to melt, decreasing glaciation. Not only are the seasons more intense in the area we think of as above the arctic circles, but more of the planet falls into the region that experiences a seasonal night, essentially a lowering of the arctic circles.

Eccentricity is the variation in the elliptical path followed by the Earth about the Sun. This path becomes more and less elongate. The ellipse is measured by comparing the semimajor axis to the semiminor axis of our orbit. The closer the lengths are to one another, the closer the orbit is to circular. This cycle varies more than obliquity, only reaching maximum elongation every fourth cycle. As a result there is a variation in the time it takes to complete a cycle ranging from 95 ka to 131 ka. There are three cycles linked with this process, two of which are notable and the third of which is very weak. The first prominent cycle is 100 ka. This is the average time it takes to move the ellipse from its maximum point of elongation through a minimum and back. The second prominent cycle is the 413 ka cycle. This is the time it takes for the cycle to move from its most extreme elongation through three more moderate cycles to the fourth cycle when it reaches its most elongate again. The third and least prominent cycle is 2.1 Ma. This is very hard to distinguish and not particularly consequential to climate change, as it is understood. Eccentricity is important to climate because the amount of solar radiation that the Earth receives varies. When the Earth is orbiting comparatively close to the Sun it is subjected to more energy input. When it is orbiting in a more elliptical path, the opposite. This process affects the globe equally and will be important at all latitudes.

The third orbital element isolated by Milankovitch is precession. This is the shortest of the elements cycling in about 20 ka. There are two parts of precession, together they are known as the precession of the equinoxes. The first part is called axial precession. This is the movement of Earth's axis in a roughly circular path, with one full turn in 23 ka. Today the northern end of Earth's axis points towards Polaris, the North Star, as the cycle proceeds our axis will rotate away from this focus and eventually back.

The second part of the cycle is called precession of the ellipse. This is the rotation of the long axis of our orbit. As a result we are at the perihelion (point closest to the Sun) at a gradually different point every year. This causes the solstices and the equinoxes to rotate around the orbit and backwards through the year. This affects where in our orbit we are receiving the most solar radiation. If we receive the most radiation when we are tilted away from the Sun, in winter, it does not have as great an impact as it would if we were tilted toward the Sun, during the summer.

These two processes operate in very much the same time scale overprinting each other and blending together. They can mainly be seen in the rock record as a strong 21.7 ka cycle. If broken down and disentangled farther a 23 ka cycle and a 19 ka cycle can be seen. This will be the most important at the equator and at low latitudes.

<u>Deep Sea Pleistocene Sediments and Milankovitch</u>

Milankovitch applied his theory first to deep sea Pleistocene sediments. In 1941 he calculated the radiation insolation curve, a representation of the amount of solar energy reaching the Earth's surface, varying depending on our orbit. He compared his findings to Pleistocene stratigraphy and recognized the four known major stages of glaciation for this time period. He saw some agreement, but not perfect. In retrospect, we notice that the faults were not with his understanding of the function of insolation, but were limited by understanding of stratigraphy of his time. It was Milankovitch's dates for the glaciations that allowed others like Emiliani and Geiss (1955) to recognize that $\partial^{18}O$ and $\partial^{16}O$ ratios were not only an indicator of water temperature, but also of continental ice.

With the understanding of magnetic reversal zones, better dates were achieved, and power spectra of the time series were done. This showed perfect 100 ka, 40 ka and 21 ka wavelengths. When these spectra were further refined two frequency peaks emerged at 19 ka and 23 ka showing the different dimensions of precession.

Another important revelation evolved from the study of the pleistocene sediments. This was the assynchronous expression of the cycles. These cycles, particularly the longer wavelengths, do not express themselves in direct relation to the energy input; there is a lag time. This apparent discrepancy is largely attributed to the high specific heat of water and the difference in the amount of energy it takes to freeze ice versus the amount it takes to melt ice.

Milankovitch cycles in the distant past

Evidence from corals from 440 Ma show that there were 11% more days per year than there are currently and that those days were longer. Gradually over the last 440 Ma the spin rate and length of our day has decreased to current levels. This kind of evidence makes us ask ourselves how applicable Milankovitch's findings are to the distant past and how far back into the past we can use these astronomical parameters as they are observed today. This question is really three questions bundled up together: how accurate are the astronomical solutions from which we are working, are there any slow changes in the system which determines the Earth's movement, and how stable is the planetary system (Schwarzacher,1993).

The general consensus is that we do understand the movement of our solar system, particularly our planet. The body of evidence to this effect is growing every year. As we learn more, the calculations seem to be reinforced by the new data. We know that our orbit is not perfectly cyclic. We do not return to the precise point of origin at the end of a cycle. However, we do return to a very close point and the change in the orbit is very predictable. This is key. While the cycles are not perfect we can calculate what they were in the past and what they will be in the future.

The geologic record of the past 500 Ma is sufficiently complete such that it is very unlikely that any major change has occurred in the form of some catastrophic event since accretion of our planet was completed. Even the major extra-terrestrial impacts like the one that caused the Sudbury complex in Ontario or the impact that is preported to define the Cretaceous-Tertiary boundary did very little to alter our orbit. Berger (1989) calculated the period lengths of the precession related cycles accounting for decreasing day length, increasing distance from the Earth to the Moon, and the changes in inertia due to tectonic arrangement over the last 400 Ma. The shorter Earth-Moon distance would cause the precessional movement to have been larger and the precession and obliquity cycles would have been shorter. By Berger's estimation in the upper Carboniferous (298 Ma) the 19,000 year cycle of precession would have taken 17,272 year and the 23,000 cycle would have taken 20,468 years. The obliquity cycle which in modern times takes 41,600 years, in the Upper Carboniferous takes 32,954 years.

<u>A test of applicability of Milankovitch cycles in the Atokan at Arrow Canyon, Clark County Nevada</u>

Arrow Canyon is a 1.5 km long cut through an upturned sequence of seemingly cyclic carbonates. These rocks were deposited in a shallow marine environment which by some paleogeographic reconstructions lay at a near equatorial latitude during the Pennsylvanian (Scotese, 2002). This environment was ideal for recording the rise and fall of sea level. It produced varied lithologies depending on the depth of water resulting from distant glaciations. The area was thought to be a passive continental margin with a carbonate ramp and unrestricted access to the open ocean.

Only a part of the Arrow Canyon section measured and described by H. Richard Lane and R.R. West in 1977 will be considered here. This section between stations A 116 and A 298 from the column developed by Lane and West has been chosen because it looks like a likely candidate to have preserved the cycles, if they indeed were occurring. Within this subsection of the larger canyon, two dates have been established. The lower date occurs at station A 186. This is based on the first appearance of the primitive foraminifer Eoschubertella ssp. According to Groves et al. this is a defining operational index for the basal Atokan sequence. This, when correlated to Eastern Europe, lies just above the Westphalian B-C boundary and is given the chronologic date of 310.8 Ma based on the dating of a coal tonstein called the Fire Clay Tonstein in the Donets Basin in the Ukraine by Groves, et al.

The second date is at the top of the considered section, station A 298. This has been identified as the Atokan-Desmoinesian boundary based on the first appearance of Wedekindellina (Heckle, 1990). This has been found to date to 309.0 Ma. So, over course of 1.8 Ma the top 167.5 meters of this section were deposited. I am going to make a projection that the rate of sedimentation was consistent throughout the canyon and therefore the previous 130.5 meters was deposited in the course of approximately 1.4 Ma. This gives us a total time span of 3.2 Ma with which we are concerned.

In this section, between stations A 103 and A 298 I have extracted 8 major bundles of cycles. These bundles are based on the changes in dominant lithology. This was almost always a variation between dominant packstone and wackestone changing into a mudstone dominant lithology and the back again. These changes were repetative and fairly regular. I placed the cycle boundary where the wackestone packstone lithology reappeared. Considering the 3.2 Ma the frequency of these cycles is about 400,000 years. This is fairly close to the 413,000 year cycle, but not exactly. I think this is a result of the last cycle not being complete with in our sample area.

Within these bundles there seems to be a smaller cyclic pattern. This pattern is more vividly expressed in some places than it is in others. For example in the twenty meters between stations A 161 and A 181 There are three minor cycles. In other areas such as between stations A 135 and A 152 there are massive beds of cherty mudstone. This I would attribute, not to the cessation of cycling, but to the depth of water not changing enough to make this deep water lithology shift.

I chose these cycles based on the model developed by Algeo et al. (1992). The model predicts that there well be a thin bedded nodular argillaceous wackestone at the base. This will be capped by a bedded chert. Above this unit will be a massive fossil bearing wackestone, a burrowed wackestone and finally by a cross bedded fossil/oolitic grainstone. Most of the time in this section the top part of the model cycle doe not appear.above the burrowed fabric wackestone. The model predicts that this cycle will range in thickness between 3 and 30 meters. Most of these fall at the smaller end of that range. In total I defined 43 minor cycles. I believe that there are places where the cyclicity of the rock is hard to see because the water at the time was a particularly high stand and the deposition surface was below a level of frequent lithology change.

In an attempt to define the frequency of this cycle we will again consider our 3.2 Ma which we have defined earlier. Within this time 43 minor cycles yield a frequency of 74,418 years. If all the cycles could be defined I think that these cycles would prove to be the obliquity cycle.

Conclusion

The cyclicity of these rocks is excellent. They repeat Algeo's model cycle in a slightly abbreviated way, again and again. The frequency of these cycles would be interesting to study in more detail and in conjunction with the sequence stratigraphy and a high resolution sea level curve of the time.

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	A	B	C	D	E	F	G	H
18	A	110	10.5	B	A			
19			11.5	F	N			
20	A	111	12	D	N			
21			12.1	D	N			
22			12.85	F	A			
23			13.05	F	N			
24			13.2	F	N			
25			13.35	D	N			
26				B	N		minor #1	
27	A	112	13.5	B	N			
28	A	113	15	B	A			
29	A	114	16.5	B	A			
30			16.65	A	N			
31			17.75	B	N			
32	A	115	18	B	C			
33			16	C	C			
34				B	A			
35	A	116	19.5	D	A			
36			20.5	B	N			
37			20.7	A	C			
38				B	N		minor #2	
39	A	117	21	A	N			
40			20.2	B	N			
41	A	118	22.5	G	N			
42	A		20.7	D	N			
43			23.3	G	N			
44	A		23.45	C	N			
45	A		23.5	B	N			
46	A	119	24	B	N			
47			24.4	F	N			
48			24.55	F	N			
49			24.8	B	N			
50			24.9	F	N			
51			25.2	B	N			
52				D	brecciated		minor #3	
53	A	120	25.5	B	N			
54	A	121	27	B	N			
55			24.2	B	N			
56			28	B	A,			
57				B	A,J			
58	A	122	28.5	D	A			
59	A	123	30	D	A			
60			28.4	C	N			
61			30.5	B	A			
62			30.55	C	N			
63			31	B	N			
64			31.15	C	N			
65			31.3	B	N		minor #4	
66			31.4	C	N			
67				D	A			

	A	B	C	D	E	F	G	H
68	A	124	31.5	D	A			
69	A	125	33	D	A			
70	A	126	34.5	B	A			
71			33.25	C	I			
72			35.45	B	A			
73	A	127	36	B	A			
74	A	128	37.5	B	A			
75			32.8	D	A			
76	A	129	39	D	A			
77			33.75	B	N			
78	A	130	40.5	B	N		minor#5	
79			41.25	B	A			
80	A	131	42	B	A			
81	A	132	43.5	B	N			
82			43.85	B	A			
83	A	133	45	B	A			
84	A	134	46.5	B	A			
85			47	C	N			
86			47.1	D	A			
87	A	135	48	D	C,A			
88	A	136	49.5	D	C,A			
89	A	137	51	D	C,A			
90	A	138	52.5	D	C,A			
91	A	139	54	D	C,A			cycle #2
92	A	140	55.5	D	A			
93	A	141	57	D	A			
94	A	142	58.5	D	A			
95	A	143	60	D	A			
96	A	144	61.5	D	A			
97	A	145	63	D	A			
98	A	146	64.5	D	A			
99	A	147	66	D	A			
100	A	148	67.5	D	A			
101	A	149	69	D	A			
102	A	150	70.5	D	A			
103	A	151	72	D	A			
104			72.8	H	A,C.G.			
105	A	152	73.5	H	A, C.G.			
106			73.7	covered				
107			74.3	D	C			
108	A	153	75	D	C		minor #6	
109			75.8	D	C			
110				B	A C			
111	A	154	76.5	D	H			
112			77.8	A				
113	A	155	78	D	A			
114	A	156	79.5	D	A			
115			80.85	B	BIOTURBATED			
116	A	157	81	D	A, QTZ			
117			81.6	[illegible]	A, QTZ			

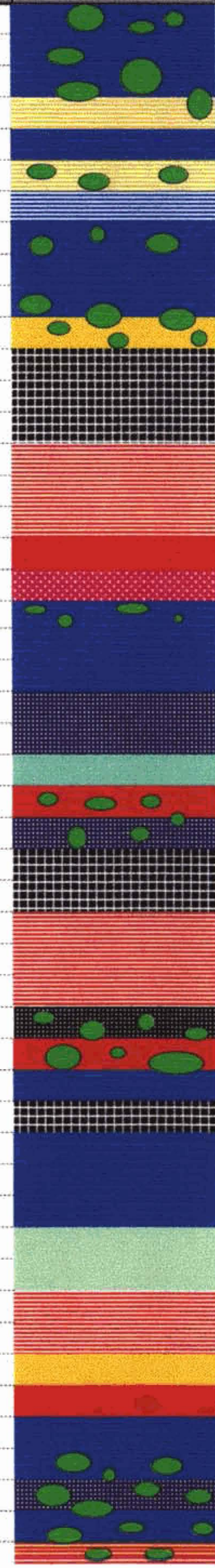
	A	B	C	D	E	F	G	H
118			82.1	F	A			
119	A	158	82.5	F	QTZ			
120			83.15	F	A			
121			83.35	A	F			
122			83.99	F	A			
123	A	159	84	C	N			
124			85	E	A			
125			81.01	C	N			
126			85.02	E	A, less			
127			85.03	H	A			
128	A	160	85.5	H	A			
129			86.2	H	A			
130			86.4	C	N			
131				H				
132		161	87	D	A			
133			83.2	E				
134			88.3	B	A, QTZ,C			
135	A	162	88.5	B	QTZ, A, C			
136	A	163	90	Qtz sst				
137			91.2	covered			minor #7	cycle#3
138	A	164	91.5	covered				
139	A	165	93	covered				
140	A	166	94.5	covered				
141			95.15	C				
142			95.3	B	A,E			
143				B	E			
144	A	167	96	B	E			
145			96.5	B	E			
146			96.6	B	J			
147			96.99	B				
148			97	D	A			
149	A	168	97.5	B	A			
150	A	169	99	B	A		minor #8	
151	A	170	100.5	B	A			
152	A	171	102	B	A			
153	A	172	103.5	B	A			
154			104.9	covered				
155		173	105	covered				
156			105.8	D	C			
157			106.2	C				
158	A	174	106.5	A	B			
159			106.75	F	C			
160			107.3	B	H,A			
161			107.7	Qtz s st				
162				H	QTZ		minor #9	
163	A	175	108	H	QTZ			
164			108.3	covered				
165			109.3	B	A			
166	A	176	109.5	B	A			

	A	B	C	D	E	F	G	H
167	A	177	111	B	C,A			
168			111.15	B	H			cycle #4
169			111.85	B	H,A			
170			112.15	F	C, H			
171				F	C,J,A			
172	A	178	112.5	D	Z,C			
173	A	179	114	D	I			
174			114.75	D	A		minor #10	
175			115.35	F	A			
176	A	180	115.5	F	A			
177	A	181	117	F	A			
178			117.4	F	N			
179			118	J	A			
180			117.41	C	C			
181			118.2	J	H			
182	A	182	117	A	A			
183			117.3	E	C			
184			119.2	H	N			
185			119.35	C				
186			119.85	H	A			
187				H	A			cycle #5
188	A	2	120	H	N			
189			120.4	H	N			
190			120.9	D	J			
191				B	A			
192	A	184	121.5	B	A			
193			122.15	B	A,J			
194			122.6	B	C			
195			114.8	B	N		minor #11	
196				A	A			
197	A	185	123	F	C			
198			123.3	D	N			
199	A	186	124.5	D	A			
200			125.3	F	A,C			
201	A	187	126	F	A		minor #12	
202	A	188	127.5	F	A			
203	A	189	129	F	A			
204			130.1	F	C			
205	A	190	130.5	covered				
206			131.3	F	C			
207			131.5	covered				
208	A	191	132	covered				
209			133.25	F	C,A			
210	A	192	133.5	F	C,A			
211			134.6	C	C		minor #13	
212			134.85	B	A			
213	A	193	135	B	N			
214			135.65	B	N			
215			136.15	B	A			
216			136.4	B	A,QTZ			

	A	B	C	D	E	F	G	H
217	A	194	136.5	B	A,QTZ			
218	A	195	138	F	A, I			
219			138.5	covered				
220	A	196	139.5	C	D			
221	A	197	141	C	D			
222			142	B	A, H			
223	A	198	142.5	B	A,H		minor #14	
224	A	199	144	C	C			
225				B	H,A			
226	A	200	145.5	C	C			
227			145.51	A	A			
228			145.86	B	N			
229			146.36	F				
230			147	B	C			
231	A	201	147	B	N			
232			148.35	B	C			
233	A	202	148.5	B	C			
234			148.95	B	H			
235	A	203	150	B	H		minor #15	
236			150.4	B	A			
237	A	204	151.5	B				
238			152.1	H	A, QTZ			
239	A	205	153	B	QTZ			
240			153.5	B	QTZ			
241	A	206	154.5	B	QTZ			
242			15	covered				
243			155.45	B	N			
244	A	207	156	B	C			
245	A	208	157.5	B	C			cycle #6
246			158.35	B	C		minor #16	
247			158.8	B	N			
248			156	B	N			
249	A	209	159	B	N			
250	A	210	160.5	B	C, H			
251			160.9	covered				
252	A	211	162	covered				
253			162.8	covered				
254				B	A			
255	A	212	163.5	A				
256			946	A				
257			163.89	B				
258			164.14	B	H		minor #17	
259			164.6	B	A			
260	A	213	165	B	A			
261			165.8	B	A, C			
262			166.3	B	N			
263	A	214	166.5	B	N			
264	A	215	168	B	N			
265			168.15	B	A			
266			168.65	C	C			

	A	B	C	D	E	F	G	H
267			169	B	A			
268	A	216	169.5	B	A, J			
269	A	217	171	B	C			
270			171.35	B	A			
271	A	218	172.5	B	A		minor #18	
272			172.75	B	N			
273			172.9	covered				
274			173.15	B	J			
275			173.4	covered				
276	A	219	174	covered				
277			175.4	C	SILT			
278	A	220	167.5	C	SILT			
279	A	221	176	C	SILT			
280			178.2	E	D			
281	A	222	178.5	D	A			
282	A	223	180	G	C		minor #19	
283			180.5	B	A			
284	A	224	181.5	B	A			
285			182.8	C				
286				C	A			
287	A	225	183	B	A,J, C			
288	A	226	184.5	B	,C			
289			185	covered				
290			185.8	B	H			
291	A	227	186	B	H			
292			186.7	covered				
293	A	228	187.5	covered			minor #20	
294			188.4	B	A			
295			188.7	B	N			
296	A	229	189	A				
297			189.2	F	C			
298	A	230	190.5	F	A			
299			190.75	B	A			
300			191.4	B	C			
301			191.85	H	N			
302	A	231	192	H	N		minor #21	
303			192.3	C	C			
304			192.6	H	N			
305			192.7	C	C			
306			193.3	B	A,C			
307	A	232	193.5	B	A			
308	A	233	195	B	N			
309	A	234	196.5	B	N		minor #22	
310			197.8	covered				
311	A	235	198	E	F			
312			198.2	covered				
313			198.8	B				
314			199.2	covered				
315	A	236	199.5	B	A			
316			199.85	covered				

	A	B	C	D	E	F	G	H
317	A	237	201	F	A			
318			201.2	F	A			
319			201.35	F	J		minor #23	
320			201.7	C				
321			202	F	J			
322			200	C				
323	A	238	202.5	E	J			
324			202.55	C	H			
325			202.65	D	A			
326		239	204	D	A			
327	A	240	205.5	F	C			
328			205.9	E	D			
329	A	241	207	E	A			
330	A	242	208.5	E	A			
331			209.5	qtz s st			minor #24	
332	A	243	210	qtz s st				
333	A	244	211.5	qtz s st				
334			211.65	F	A,H			
335			212.65	B	H,A,J			
336	A	244	212	F	C			
337			213.15	E	C, J		minor #25	
338			214.15	E	J			
339	A	246	213.5	E	J,C			cycle #7
340			213.85	B	J,C,A			
341	A	247	215	covered				
342	A	248	216.5	covered				
343			217	covered				
344				covered	A			
345	A	248	193.5	covered				
346			193.75	F	H			
347	A	249	216	F	H		minor #26	
348				D	cleaner			
349			219.55	C	I			
350			219.65	F	J			
351			219.85	F	J			
352	A	251	220	F	J			
353			198.25	D	A			
354			220	F	N			
355			199.3	D	A			
356	A	252	199.5	D	A			
357	A	253	224	D	A			
358	A	254	225.5	D	A			
359			225.7	D	A		minor #27	
360			225.9	F	C, A, B			
361			226.5	D	C			
362	A	255	227	B	A			
363			228.15	B	C C C			
364	A	256	228.5	B	C C C			
365			228.8	B	J, A			
366	A	257	230	B	J, A, C			

	A	B	C	D	E	F	G	H
367			230.95	B	J, A ,C			
368	A	258	231.5	B	J, A ,C			
369			232.2	B	N			
370			232.4	F	C			
371			232.7	B	A			
372				F	C		minor #28	
373	A	259	232	B	C,A,J			
374			234.8	B	fenestrate			
375			235.15	B	A			
376			235.5	B	A			
377	A	260	233.5	F	N			
378			233.55	covered				
379	A	261	235	covered				
380			235.3	covered				
381			236.1	D	C			
382			236.1	D	C			
383	A	262	236.5	D	C			
384			236.6	D	H			
385				H	A at top			
386	A	263	238	B	J		minor #29	
387	A	264	239.5	B	J			
388	A	265	243	B	J			
389			244	C	Q T Z			
390	A	266	244.5	C	QTZ, H			
391			245.3	H	A, SK			
392	A	267	246	D	A			
393	A	268	247.5	C	C		minor #30	cycle #8
394			248	covered				
395	A	268	248	covered				
396			248.5	D	C C			
397	A	270	226.5	D	C			
398			251.3	D	A , C			
399	A	271	252	covered				
400			253.3	D	C		minor #31	
401			252.8	B	N			
402				covered				
403			253.35	B	N			
404	A	272	253.5	B	N			
405			229.9	B	N			
406			255	H	J			
407	A	273	252	H	J			
408			256.025	D	C			
409	A	274	256.5	D	C			
410			257.2	F				
411	A	275	258	D	B		minor #32	
412			258.35	B	A			
413	A	276	259.5	B	A			
414			260.5	C	A			
415			260.9	B	A		minor #33	
416	A	277	261	D	C			

	A	B	C	D	E	F	G	H
417	A	278	262.5	D	C			
418			263	H	QTZ, SK			
419	A	276	263.5	D	A			
420			264	D	C		minor #34	
421			264.7	D	A			
422	A	280	264	covered	D			
423			267.6	H	N			
424	A	281	266.5	H	N			
425			267.4	B	N		minor #35	
426			267.41	C	C C			
427	A	282	268	G				
428			268.35	D	N			
429			269.4	D	A			
430	A	283	269.5	D	C C			
431			270.3	C	C C			
432			270.4	B	A		minor #36	
433	A	284	271	B	N			
434			271.25	C	C C			
435			271.7	B	H,A			
436			271.95	B	C		minor #37	
437			272.15	B	A			
438				B	C			
439	A	285	272.5	C	C C			
440			272.6	B	A			
441			271.25	H	C			
442			271.7	B	A			
443	A	286	274	B	N			
444			274.5	A	A		minor #39	
445			274.65	B	A			
446			275	B	N			
447	A	287	275.5	B	A			
448			260.65	B	N			
449			276.8	D	C C			
450	A	288	277	C	C C			
451			261.7	C	C C			cycle #9
452			278.05	D	A		minor #40	
453	A	289	278.5	D	A			
454			278.95	A	A			
455	A	290	280	A	A			
456			280.75	D	A			
457	A	291	281.5	D	A			
458	A	292	283	D	A		minor #41	
459	A	293	284.5	B	N			
460			284.9	D	A			
461	A	294	286	C	C			
462			286.25	covered				
463			287.25	B	G			
464	A	295	287.5	B	A		minor #42	
465			287.9	B	G			
466			288.75	B	A			

	A	B	C	D	E	F	G	H
467	A	296	289	D	C C			
468			289.65	D	C			
469			290.05	D	A		minor #43	
470			290.3	D	C C			
471			290.4	D	A			
472				C	D			
473	A	297	290.5	D	A			
474			290.65	covered				
475	A	296	292	covered				
476								